DESCRIPTION

ENGINE CONTROL SYSTEM, VEHICLE HAVING THE SAME, METHOD FOR CALCULATING FUEL CENTER OF GRAVITY, AND METHOD FOR CONTROLLING ENGINE

Technical Field

[0001]

The present invention relates to an engine control system, a vehicle having the same, a method for calculating the fuel center of gravity of an engine, and a method for controlling an engine.

Background Art

[0002]

A well-known method for optimizing the ignition timing of spark ignition internal combustion engines is a method of determining ignition timing on the basis of negative ion current in the cylinder (e.g., refer to Patent Document 1). In the method disclosed in Patent Document 1, negative ion current flowing in the cylinder directly after ignition is measured, and the time from the ignition at which the value of the negative ion current becomes the maximum is determined. Then the time difference between the determined time and minimum spark advance for best torque (MBT) is calculated, and the calculated time difference is added to or subtracted from

the preceding ignition timing to thereby determine the present ignition timing.

Patent Document 1: JP-A-6-33855

Disclosure of the Invention

Problems to be Solved by the Invention

[0003]

The conventional ignition timing control is based on the following assumption:

(1) The peak position of the negative ion current after ignition has correlation with combustion pressure.

(2) The peak of combustion pressure is at 15° after top dead center during operation at which ignition timing agrees with MBT.

(3) Therefore, adjusting the ignition timing so that the peak position of the negative ion current comes to 15° after top dead center enables the ignition timing to agree with MBT.

[0004]

However, the peak position of the combustion pressure actually depends on the operating state. Item (2) is therefore an assumption that holds only in a limited operating region. Specifically, for example, at MBT during which combustion speed is low, the ion current peak position does not come to 15° after top dead center. Accordingly, the conventional control could not make the ignition timing agree with MBT in a wide operating region.

[0005]

The invention has been made in view of the problems of the conventional method. Accordingly, it is an object of the invention to provide a system or method capable of control such as making ignition timing agree with MBT to thereby increase fuel efficiency, reduce exhaust gas, or improve drivability without measuring torque and combustion pressure.

Means for Solving the Problems

[0006]

An engine control system according to the invention includes: an ion current measuring unit that measures the negative ion current in a combustion chamber of an engine; a crank-angle measuring unit that measures an engine crank angle; and a controller that controls the engine on the basis of a first crank angle at which the increase rate of the negative ion current against the crank angle becomes more than a first specified value and a second crank angle at which the increase rate becomes a second specified value after becoming the first specified value.

[0007]

A method for calculating the fuel center of gravity of an engine according to the invention includes the steps of: measuring the negative ion current in a combustion chamber of the engine; determining a first crank angle at which the increase rate of the negative ion current against the engine

crank angle becomes more than a first specified value; determining a second crank angle at which the increase rate becomes a second specified angle after becoming the first specified angle; and calculating the fuel center of gravity from the first crank angle and the second crank angle.

[0008]

A method for controlling the operation of an engine according to the invention includes the steps of: measuring the negative ion current in a combustion chamber of the engine; determining a first crank angle at which the increase rate of the negative ion current against an engine crank angle becomes more than a first specified value; determining a second crank angle at which the increase rate becomes a second specified angle after becoming the first specified angle; and controlling the engine on the basis of the first crank angle and the second crank angle.

[0009]

According to the invention, an engine is controlled or the fuel center of gravity is calculated on the basis of the rising point and the peak point of the negative ion current on a negative ion current characteristic curve. Thus, as distinct from the control or calculation based only on the peak point of negative ion current, correct control or calculation can be achieved even when the peak point shifts as the operating state changes. Accordingly, control of making the ignition

timing agree with MBT can be achieved in a wide operating region without measuring torque and combustion pressure.

Advantages of the Invention

[0010]

Thus, the invention enables ignition timing to be agreed with MBT in a wide operating state such as at low combustion speed, thus increasing fuel efficiency, reducing exhaust gas, or improving drivability.

Brief Description of the Drawings

[0011]

[Fig. 1] Fig.1 is a side view of a motorcycle according to an embodiment.

[Fig. 2] Fig. 2 is a schematic diagram of an engine.

[Fig. 3] Fig. 3 is a characteristic diagram of negative ion current and combustion pressure against crank angles.

[Fig. 4] Fig. 4 shows characteristic curves of negative ion current plotted against crank angles.

[Fig. 5] Fig. 5(a) shows characteristic curves for heat rate and combustion mass ratio; Fig. 5(b) shows a characteristic curve for negative ion current.

[Fig. 6] Fig. 6 is a graph showing the relationship between engine speed and ignition timing, and fuel center of gravity and so on.

[Fig. 7] Fig. 7 is a graph showing the relationship between ignition timing and torque, fuel center of gravity and so on.

[Fig. 8] Fig. 8 is a graph showing the relationship between ignition timing and torque, fuel center of gravity and so on.

Description of Reference Numerals and Signs

[0012]

1: engine

5: combustion chamber

14: ignition plug (ion-current measuring unit)

16: engine control unit (controller)

19: crank-angle sensor (crank-angle measuring unit)

100: motorcycle (vehicle)

B: first crank angle

C: second crank angle

G: third crank angle

Best Mode for Carrying Out the Invention

[0013]

An embodiment of the invention will be described with reference to the drawings.

[0014]

Referring to Fig. 1, a vehicle according to the embodiment is a vehicle having an engine 1, specifically, a motorcycle 100 which is a kind of saddle-type vehicle. The motorcycle 100 has a body 101, a front wheel 102, and a rear wheel 103. The body 101 has an air intake port 104, an air cleaner 105, the engine 1, and a muffler 106. The air intake port 104 and the air cleaner 105 are connected to each other

via an intake duct 107. The air cleaner 105 and the engine 1 are connected together via an intake pipe 108. The engine 1 and the muffler 106 are connected via an exhaust pipe 109.

[0015]

The engine 1 is a spark-ignition internal combustion engine, which is, in this embodiment, of a water-cooled four-cycle multiple cylinder type. Alternatively, the engine 1 may be of an air-cooled type. The number of cylinders of the engine 1 is not limited but may be, for example, one.

[0016]

Referring to Fig. 2, the engine 1 includes a crankcase 2, a cylinder block 3 fixed onto the crankcase 2, a cylinder head 4 fixed onto the cylinder block 3, and a head cover (not shown) fixed onto the cylinder head 4. The cylinder block 3 has a cylinder bore 3a therein, in which a piston 6 is disposed. The piston 6 connects to a connecting rod 7. The connecting rod 7 connects to a crankshaft 8 disposed in the crankcase 2.

[0017]

The cylinder head 4 has a recess 4a on the surface adjacent to the cylinder block 3. The recess 4a, the piston 6, and the cylinder bore 3a define a combustion chamber 5. The cylinder head 4 has an intake valve opening 4b and an exhaust valve opening 4c which are open to the recess 4a. The cylinder head 4 also has an intake valve 9 and an exhaust valve 10 for opening and closing the intake valve opening 4b and the exhaust valve

opening 4c, respectively.

[0018]

The intake valve 9 and the exhaust valve 10 are opened or closed by an intake camshaft 11 and an exhaust camshaft 12, respectively. The intake camshaft 11 and the exhaust camshaft 12 connect to a variable valve timing mechanism 13. The variable valve timing mechanism 13 receives a valve-timing control signal *a* from an engine control unit (hereinafter, referred to as an ECU) 16 to control the open-close timing of the intake valve 9 and the exhaust valve 10 by the intake camshaft 11 and the exhaust camshaft 12, respectively.

[0019]

An ignition plug 14 is placed in the cylinder head 4. The ignition plug 14 is disposed substantially at the center of the recess 4a. The electrode of the ignition plug 14 is exposed to the inner surface of the recess 4a. The ignition plug 14 connects to an igniter 15. The igniter 15 receives an ignition-timing control signal *b* from the ECU 16 to control the spark generation timing of the ignition plug 14.

[0020]

In this embodiment, the ignition plug 14 is used also as a negative ion current probe. The ignition plug 14 connects to a positive electrode 17a of a buttery 17. A negative electrode 17b of the buttery 17 connects to the cylinder head 4 via a wattmeter 18 for grounding. Thus the ignition plug

14 is always positively charged. Obviously, the negative ion current probe may be provided separately.

[0021]

The engine 1 includes a crank-angle sensor 19 and a knock sensor 20 for detecting knocking. Detection signals from the crank-angle sensor 19 and the knock sensor 20 are input to the ECU 16. As will be described later, when the occurrence of knocking is detected by the knock sensor 20, the ignition timing control by the ECU 16 is restricted.

[0022]

The negative ion current generated in the combustion chamber 5 varies as the combustion progresses. Specifically, when the ignition plug 14 ignites the air fuel mixture in the combustion chamber 5, a first chemical action is activated, so that electrons in atoms or molecules collide with one another to generate energy. The atoms or molecules thus come into an excited state accompanied by heat generation sufficient to shift to an energy state higher than a normal stable state. With the shifting to the excited state, chemical light emission around ultraviolet rays occurs to increase positive ions. As a result, the negative ion current in the combustion chamber 5 increases. The negative ion current is collected by the ignition plug 14 that is used also as an ion-current probe and the detection value of the wattmeter 18 is input to the ECU 16.

[0023]

Fig. 3 shows characteristic curves of negative ion current E and combustion pressure P plotted against crank angles. As shown in Fig. 3, the characteristic of the negative ion current E exhibits almost the same tendency as that of the combustion pressure P. The negative ion current E can therefore be used as information indicative of changes in combustion pressure P, flame area, or heat generation.

[0024]

However, the crank angle at which the combustion pressure P becomes the maximum depends on the operating state of the engine 1. Accordingly, the peak position of the negative ion current E depends on the operating state of the engine 1 (refer to Fig. 4, which is merely a conceptual diagram for explanation, and is not based on actual measurement data). Therefore, the control based only on the peak position of the characteristic curve of the negative ion current E cannot flexibly cope with changes in engine load, so that it cannot be applied to a wide variety of operating state.

[0025]

However, the inventor has realized the following points. Specifically speaking, as has been described, even when the ignition timing is at MBT, the characteristic curve of the negative ion current E varies as the operating state of the engine 1 varies (refer to curves E1 and E2 of Fig. 4), so that

the crank angle corresponding to the peak position of the characteristic curve changes. However, crank angles that change little even if operating state changes can be calculated from a plurality of crank angles corresponding to a plurality of points on the characteristic curve, such as crank angles corresponding to fuel center of gravity. Point P0 in Fig. 4 indicates the point corresponding to such a crank angle. Controlling based on this crank angle enables flexible response to fluctuations in load, allowing control applicable to wide operating regions without measuring torque and combustion pressure.

[0026]

A specific example of the control will be described hereinbelow. Operation control for adjusting ignition timing to MBT will first be described.

[0027]

Fig. 5(b) shows changes of the negative ion current E plotted against crank angles; Fig. 5(a) shows changes of heat rate D and combustion mass ratio F. Referring to Fig. 5(b), symbol A indicates a crank angle for an ignition point; symbol B indicates a crank angle for any rising point of the ion current on the ion-current curve (hereinafter, referred to as a first crank angle); and symbol C indicates a crank angle for any peak point of the ion current (hereinafter, referred to as a second crank angle).

[0028]

As shown in Fig. 5(a), the increase of the ion current for the crank angle at the rising point becomes from less that a specified value (hereinafter, referred to as a first specified value) to more than the specified value. On the other hand, at the peak of the ion current, the increase falls from the first specified value or more to a specified value (hereinafter, referred to as a second specified value, which may be different from or equal to the first specified value) or less. Accordingly, the point at which the increase becomes the first specified value or more can be referred to as a rising point, and the point at which the increase becomes the first specified value and then falls to the second specified value or less can be referred to as a peak point. The method for determining the rising point and the peak point is not limited at all. For determining the rising point and the peak point, there is no need to calculate the increase; for example, the rising point and the peak point can be determined by comparing the values of the ion current and a predetermined threshold.

[0029]

In this embodiment, the first crank angle B is set to a crank angle corresponding to the rising point of the ion current curve, and the second crank angle C is set to a crank angle corresponding to the peak point of the ion current curve. The first crank angle B and the second crank angle C, however,

may not exactly agree with the rising point and the peak point, respectively, but may be slightly off the rising point and the peak point because of measurement error or disturbance. In short, the first crank angle B and the second crank angle C have only to be substantially regarded as the rising point and the peak point, respectively.

[0030]

As shown in Figs. 5(a) and 5(b), the negative ion current generating point (the position corresponding to the first crank angle B) to be regarded as the beginning of combustion is the point that ignition delay time has passed after the discharge of the ignition plug 14, and at which heat generation begins by the start of the initial combustion. The peak point thereafter (the position corresponding to the second crank angle C) is the point at which the heat generation during combustion becomes the maximum. Accordingly, the midpoint thereof is estimated to correspond to the fuel center of gravity.

[0031]

The substantially middle point between the first crank angle B and the second crank angle C can therefore be regarded as a crank angle (hereinafter, referred to as a third crank angle) G corresponding to the fuel center of gravity. Thus, the fuel center of gravity can be calculated from the first crank angle B and the second crank angle C. As will be described

later, when the ignition timing is at MBT, the fuel center of gravity does not vary greatly even if the load varies. Accordingly, in this embodiment, the ECU 16 presets the crank angle corresponding to the fuel center of gravity at MBT as a target crank angle, and controls the ignition timing of the igniter 15 so that the third crank angle determined by measuring the negative ion current agrees with the target crank angle.

[0032]

When the ignition timing is at MBT, the fuel center of gravity does not vary greatly by load fluctuations. Accordingly, the target crank angle may be set not to be varied according to the load conditions of the engine 1. The target crank angle may be a fixed value. On the other hand, the target crank angle may depend on the individual difference or secular changes of the engine 1, or may be appropriately varied on the basis of an operational expression or a table containing parameters.

[0033]

Fig. 6 shows the relationship between engine speed and ignition timing, fuel center of gravity, and so on. The fuel center of gravity is calculated from the first crank angle B and the second crank angle C. Referring to Fig. 6, the first crank angle B, the second crank angle C, and the third crank angle G indicate "ignition angle", "the end of combustion", and "the fuel center of gravity", respectively. The interval

between A and B indicates an ignition delay period, and the interval between B and C indicates combustion period. In this embodiment, the target crank angle corresponding to the fuel center of gravity is set at about 1-5° before top dead center. The ignition timing is feed-back controlled so that the third crank angle G becomes the target crank angle (1-5° before the top dead center).

[0034]

Fig. 7 shows the relationship between ignition timing and torques and fuel center of gravity, and so on. As shown in Fig. 7, the torque depends on ignition timing, and becomes the maximum when the ignition timing is at MBT. On the other hand, as the ignition timing advances to the top dead center, the fuel center of gravity shifts from the position of after top dead center to the position of before top center. The torque therefore increases as the fuel center of gravity moves from the position of after top center to the position of before top center, and becomes the maximum when the fuel center of gravity is about at 2-3° before the top dead center, and in turn decreases as the fuel center of gravity moves toward the before top center.

[0035]

The graph shows that when the ignition timing is controlled so that the third crank angle G (a crank angle corresponding to the fuel center of gravity) becomes 2-3° before

top dead center, the ignition timing becomes 35-36° before top dead center, so that the ignition timing agrees with MBT.

[0036]

As has been described, by the control according to the embodiment, the target value of the third crank angle G does not vary significantly by the fluctuation of the operating state. Accordingly, in the case of complicatedly varying the lift amount and open-close timing of the intake valve 9, or in the case of simply varying engine load conditions such as rotation speed and throttle opening, the ignition timing can easily be agreed with MBT by the above-described control using the measurement of the negative ion current in the combustion chamber 5.

[0037]

An experiment by the inventor shows that, for example, for MBT at a specific operating state x of a specific internal combustion engine, the first crank angle B at which a negative ion current at the beginning of combustion starts to generate was 11° before top dead center, and the second crank angle C at which the negative ion current becomes to the peak thereafter was 9° after top dead center. The difference between the second crank angle C and the first crank angle B was 20°, and the third crank angle G in the center thereof was 10° delayed behind the first crank angle B, or 1° before top dead center.

[0038]

Then, for the internal combustion engine, the third crank angle G was measured under different load conditions. Specifically, the load conditions were changed by changing the throttle opening or rotation speed. The measurement of the third crank angle (the angle in the middle between the first crank angle B and the second crank angle C) G shows that although the rising point and the peak point of the negative ion current curve varies, the third crank angle G is always 1° before top dead center under any load condition. Briefly, with the internal combustion engine, the third crank angle G at which the ignition timing is at MBT was the same at all load conditions. For example, the comparison between Figs. 7 and 8 indicating torque characteristic etc. under different load conditions shows that the third crank angles G at which the ignition timing agrees with MBT are both 1° before top dead center.

[0039]

Under the same conditions of bore/stroke ratio and connecting rod ratio (λ), the combustion speed changes as the rotation speed and load of the engine 1 change, so that the first crank angle B and the second crank angle C determined from the negative ion current changes. However, the third crank angle G corresponding to the fuel center of gravity is held constant at MBT.

[0040]

Conventionally, heat generation has been estimated from

pseudo combustion mass ratio converted from combustion pressure. According to the estimation, about 30% of the entire heat generation distribution at MBT has been estimated to be located before top dead center, while the remaining 70% has been estimated to be located after top dead center, and the fuel center of gravity has been estimated to be located after top dead center.

[0041]

However, by the method for calculating fuel center of gravity according to the embodiment, the fuel center of gravity is in the vicinity of top dead center, or more specifically, 1-5° before top dead center. The difference may be by the following reasons: most of negative ions during combustion generate at the excitation of cool flame and blue flame. However, the heat generation determined from combustion pressure is the result of light emission of amplitude transition such as flaming reaction after cool flame and blue flame, or solid-state radiation around infrared rays. Accordingly, the conventional method takes little thought of the excitation, so that the fuel center of gravity determined from combustion pressure may be delayed behind the fuel center of gravity based on the negative ion current as in the embodiment.

[0042]

The control method according to the embodiment is a

method of controlling the engine 1 by measuring a negative ion current which is unpaired electrons during true combustion, and controlling the engine 1 on the basis of the negative ion current, not by estimating an instantaneous value of the thermal conductivity of combustion gas from combustion pressure as in the past. Thus, the embodiment can reduce errors in calculating the fuel center of gravity, thus increasing control accuracy. Also, the embodiment can facilitate control of the engine 1 without a sensor in the combustion chamber 5.

[0043]

While the control according to the embodiment is such that ignition timing is adjusted to MBT so as to obtain a maximum torque, the invention is not limited to that.

[0044]

For example, in an operating state in which knocking may occur, knocking can be prevented by disabling the control or setting the target value of the third crank angle G later than the target value of the embodiment (a target value for MBT). It is also possible to prevent knocking in a manner detecting knocking with the knock sensor 20, and disabling the control according to the detection result or by setting the target value of the third crank angle G to the delayed position.

[0045]

The fuel center of gravity by the negative ion current varies significantly at flame off due to exhaust gas

recirculation (EGR) in which exhaust gas is recirculated in intake gas, a lean-burn air-fuel ratio state, or a stratified-charge combustion state. Thus, it is also possible to control the EGR rate and air-fuel ratio on the basis of the fluctuations of the fuel center of gravity per unit time to prevent flame off. In short, the control according to the invention may be achieved to prevent the flame off of the engine 1.

[0046]

For EGR (since the structure for EGR is well known, a description thereof will be omitted), it is possible to calculate a third crank angle corresponding to the fuel center of gravity by the above-described method, and calculate the fluctuation of the third crank angle, and to control the EGR rate so as to decrease with increasing fluctuation. This enables control of the EGR rate without a specific sensor and can prevent flame off of the engine 1.

[0047]

It is also possible to calculate a third crank angle corresponding to the fuel center of gravity by the above-described method, and calculate the fluctuation of the third crank angle, and to control the open-close timing of the intake valve 9 and the exhaust valve 10 of the engine 1 so that the overlap period of the intake valve 9 and the exhaust valve 10 decreases with increasing fluctuation. This enables

control of valve timing without a specific sensor and can prevent flame off of the engine 1.

[0048]

Thus, according to the embodiment, ignition timing can be agreed with MBT under a variety of operating states including decreased combustion speed, thereby improving fuel efficiency, decreasing exhaust gas, and increasing drivability. Also with a variable valve timing mechanism that complicatedly and variably controls the lift amount and open-close timing of an intake valve or when engine load conditions such as rotation speed and throttle opening are simply varied, fro example, the ignition timing can easily be agreed with MBT, allowing an optimum or preferable combustion state to be achieved. Also controlling ignition timing so that fuel center of gravity is delayed behind MBT can prevent knocking and reduce the generation of NOx of exhaust gas components.

[0049]

The calculation of the fuel center of gravity and operation control according to the embodiment are based on the characteristic of negative ion current for a crank angle sensed by the crank-angle sensor 19. However, the "crank angle" of the invention is noting but a parameter indicative of the process of combustion; parameters that may be technical equivalence to the crank angle can also be regarded as the "crank angle". This is because such parameters have

one-to-one correspondence with the crank angle. Accordingly, for example, it is also possible to specify the rising point of negative ion current on the basis of the actual crank angle, while to specify the peak point on the basis of a parameter (e.g., elapsed time) other than the actual crank angle.

[0050]

Although the operation control system for the engine 1 according to the embodiment is mounted to the motorcycle 100, the engine control system according to the invention is not necessarily mounted to vehicles. For example, the operation control system may be mounted to engine testing units, performance evaluation units, or applicable tools.

Industrial Applicability

[0051]

The invention is advantageous to vehicles such as motorcycles and control of the engines of the vehicles.